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Short communication

Sediment contribution from Israel's coastal cliffs into the Nile's littoral cell and its significance to cliff-retreat mitigation efforts

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ABSTRACT

We quantify the volumetric erosion of Israel's actively retreating Mediterranean coastal cliffs between 2006 and 2015 with airborne LiDAR. Our results reveal annual sand contribution of ~45,000 m^3 from the coastal cliffs into the Nile's littoral cell (NLC), which amounts to ~50% of the annual long-shore sand transport previously measured at the northern termination of the NLC. Accordingly, we find that implementation of cliff-retreat mitigation engineering efforts planned for Israel's coastline can lead to a sand deficit in the NLC that may result in increased beach erosion.

1. Introduction

In 2013 the government of Israel initiated a national mitigation program aimed to prevent further collapse and retreat of the country's Mediterranean coastal cliffs. The goals of this large-scale program are to protect infrastructure and property proximal to the cliff and to conduct long-term maintenance and monitoring of the coastal cliffs (www.mccp.co.il). Previous studies conducted along California's eroding sea cliffs demonstrated that retreating sea cliffs can be significant contributors of sand to the coastal sediment budget (Runyan and Griggs, 2003; Limber et al., 2008; Young et al., 2010) and thus the impact of cliff-retreat mitigation efforts on the coastal sediment budget needs to be quantified and taken into consideration (Runyan and Griggs, 2003). Here, we use new data to quantify the contribution of sediment eroded from Israel's coastal cliffs to long-shore sediment transport (LST) along the Nile's littoral cell and examine the possible impact of cliff-retreat mitigation, once achieved, on coastal sediment budget and dynamics.

2. Background

2.1. The Nile's littoral cell

The Nile littoral cell (NLC) spans 650 km along the SE Mediterranean, from Abu Quir Bay near Alexandria, Egypt, up to Haifa Bay in northern Israel (Inman and Jenkins, 1984) (Fig. 1). The cell's primary source of sand is the Nile River and delta, from where wave induced long-shore currents transport the sand along the coast up to the final depositional sink at Haifa Bay (Goldsmith and Golik, 1980; Carmel et al., 1985; Golik, 1993; Golik, 2002; Zviely et al., 2006; Klein et al., 2007).

Annual sand flux at the head of the NLC is estimated at 860,000–1,000,000 m^3/yr (Inman et al., 1976; Inman and Jenkins, 1984). The net flux of LST decreases with distance from the Nile and is estimated to be 450,000 m^3/yr at Ashkelon and about 100,000 m^3/yr at Tel Aviv/Herzlia (Perlin and Kit, 1999) (Fig. 1). Zviely et al. (2007) report an annual average of 80,000–90,000 m^3 of sand deposition at Haifa Bay during the past ~8000 years. They further conclude that this rate has not changed significantly over the past 75 years despite the construction of Aswan High Dam (completed 1964) as well as other marine structures along the NLC, such as commercial ports, power-plant cooling basins and recreational marinas. The predominately carbonate terrain found north of Ashkelon accounts for negligible input of terrestrial sand from drainage systems into this part of the NLC.

2.2. Israel's Mediterranean coastal cliffs

Coast parallel ridges, comprised of a late Pleistocene to early Holocene sequence of Nilotic eolianites and buried soils characterize Israel's ~140 km long Mediterranean coastline between Ashkelon and Haifa bay (Tsoar, 2000; Frenchen et al., 2001; Almagor, 2005; Harel et al., in press). Sand-dominated beaches typically separate the water line from the coastal plains or the sea cliffs, which characterize ~40 km of Israel's

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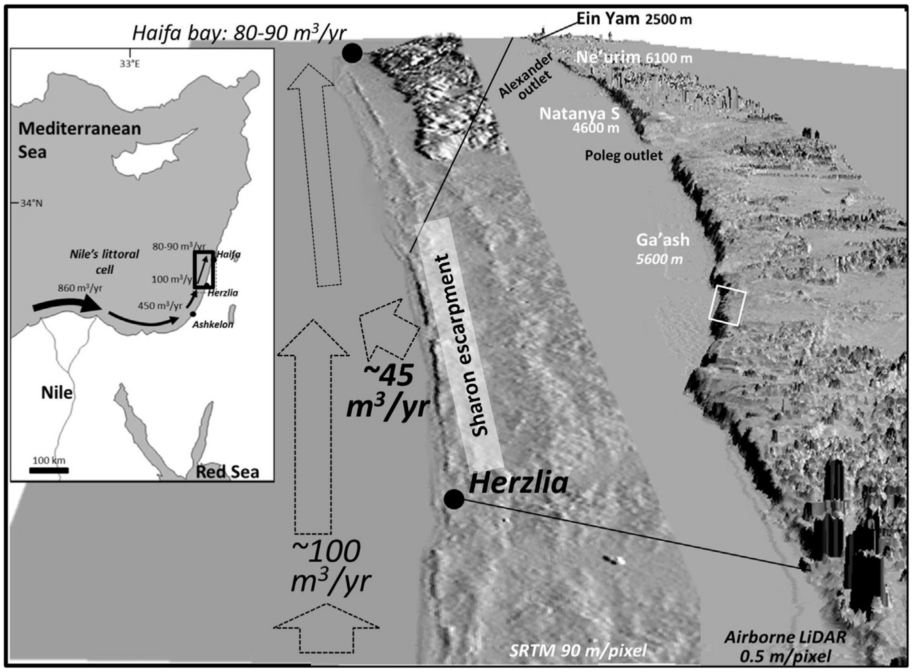

Fig. 1. Sediment budget along the Nile's littoral cell. *Left* — Location map with previously published sediment transport rates (in 10^3 m^3/yr). Boxed area is enlarged to the right. *Center* — Shaded relief perspective view of the northern termination of the Nile's littoral cell consisting of the ~30-km-long Sharon eolianite escarpment and the 40-km-long sand-dominated shore north of it until Haifa bay. *Right* — The Sharon escarpment and its four segments. White box is location of Fig. 2.

coast line. These sea cliffs are coast-parallel erosional features that are carved into the eolianite ridges. The exposed lithological units of the cliff typically consist of 50%–100% sand content (Perath and Almagor, 2000).

This study focuses on the coastal cliffs located north of Herzlia where they form a fairly continuous sea-cliff escarpment, termed herein as the 'Sharon Escarpment' (Fig. 1). The average height of the Sharon escarpment is 26 m. It forms a generally linear NNE-striking feature that is parsed by outlets of the Poleg and Alexander streams and the cliff-top city of Natanya into four contiguous uninterrupted 'natural' segments: Ga'ash (5.6 km), Natanya S. (4.6 km), Ne'urim (6.1 km) and Ein Yam (2.5 km) (Table 1).

The Sharon escarpment is currently retreating at <0.1 m/yr, which is comparable to the background rate of coast-parallel retreat determined for the escarpment since the mid Holocene (i.e., <0.01–0.09 m/yr). These rates were determined using geological observations such as the width of partially submerged erosional platforms (Mushkin et al., in review) and archeological observations (Barkai et al., in review). It therefore appears that in terms of volumetric contribution to the NLC, coastal cliff erosion has been contributing sediment at a fairly constant rate over the past several thousand years. Here, we measure the annual contribution of sediment eroded from the Sharon escarpment into the NLC between 2006 and 2015 and quantify, for the first time, the sediment deficit in LST that can be expected once effective cliff protection is achieved.

3. Methods

Retreat of the Sharon escarpment is primarily driven by gravitational collapse of the cliff that is commonly triggered by wave-induced basal scouring (Perath and Almagor, 2000; Katz and Mushkin, 2013). Typically, the cliff-collapsed material is transiently accumulated along the cliff's base until continuous wave scouring ultimately erodes it seaward from the shore platform to allow a new cliff-collapse cycle (Arkin and Michaeli, 1985; Perath and Almagor, 2000; Katz and Mushkin, 2013). Here, we used airborne LiDAR to quantify this sea-cliff erosion process (Young and Ashford, 2006). Utilizing data from 2006 (0.5 pts/m^2) and

Table 1
Erosion and sediment contribution from the Sharon escarpment into the NLC between 2006 and 2015.[a]

Cliff segment	Length (m); avg. height (m)	Erosion volume ΔV (m^3)	Normalized erosion volume (m^3/km^2)[b]
Ein Yam 32.447°N/34.878°E 32.414°N/34.871°E	2500; 14	25,491 ± 7647	728,314 ± 218,494
Ne'urim 32.383°N/34.862°E 32.333°N/34.850°E	6100; 26	58,163 ± 17,449	366,727 ± 110,018
Natanya South 32.323°N/34.847°E 32.280°N/34.835°E	4600; 30	82,863 ± 24,859	600,456 ± 180,137
Ga'ash 32.263°N/34.830°E 32.195°N/34.806°E	5600; 29	115,923 ± 34,777	713,811 ± 214,143
All	18,800; 26	282,440 ± 84,732	577,823 ± 173,347

[a] Data (airborne LiDAR) acquisition dates: 3/2006; 2/2015, 8.9 years.
[b] Erosion volume normalized to cliff area.